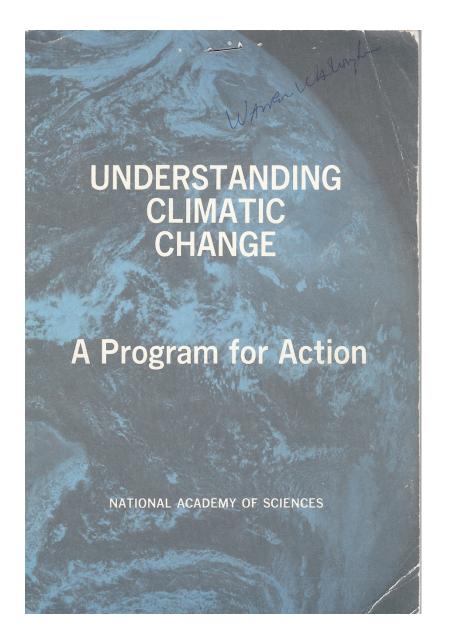


#### Outline

- First climate model intercomparison motivation
- FANGIO the move from single model analysis to comparing model results – the beginning of cloud feedback
- AMIP I atmosphere only models
- AMIP II yet more atmospheric models
- CMIP the beginning of coupled models
- CMIP3 model intercomparison goes big time
  - Nobel Prize
- CMIP5 is more better?



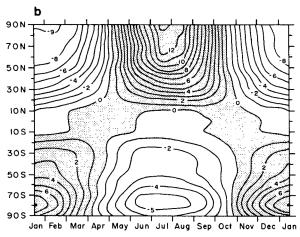
Courtesy of Warren Washington

#### 1975

- 1) Establish a national climatic research program with international coordination;
- 2) Establish a climatic data analysis program, to study the impact of climate change on food, water, and energy supplies;
- 3) Develop a climatic index monitoring program . . . a national watchdog for climate change;
- 4) Establish a climatic modeling and applications program (CMAP), and explore possible future climates using coupled general circulation models (GCMS);
- 5) Adopt and further develop an international climatic research program (ICRP); and
- 6) Develop an international paleoclimatic data network for the reconstruction of past climates.

#### 1978

- Global Atmospheric Research Program meeting on model "intercomparison"
- W. Lawrence (Larry) Gates helped organized
  - Insisted on similar formats and plots
  - Was a "beauty" contest
  - Suki Manabe of GFDL won the prize



The goal: to make the plots look alike as much as possible

"North on the left" for zonal plots

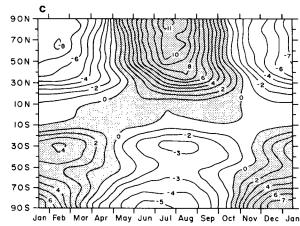


FIG. 8. Zonal mean seasonal anomaly of mass-weighted tropospheric temperature (K) from (a) Oort (1983), (b) SDM, (c) GCM.

# Beginning of an organized climate model intercomparison

- Robert D. (Bob) Cess (retired Leading Professor at SUNY Stony Brook)
  - Radiative transport classic text on radiative heat transfer – decided to look at earth's atmosphere
    - Also was considered a leader in planetary atmospheres

Met at a meeting in Dushanbe

how to better understand the processes important to model sensitivity

~1982 – Bob formulated a strategy



# Cess and Potter paper (AKA the "Cess Experiment")

- Actually Bob's work .. I did the calculations and helped with the ideas
  - Simple experiment still in use today

TABLE 1. Changes in Global Mean Surface Air Temperature Due to Doubling Atmospheric CO<sub>2</sub>, as Predicted by Five GCMs

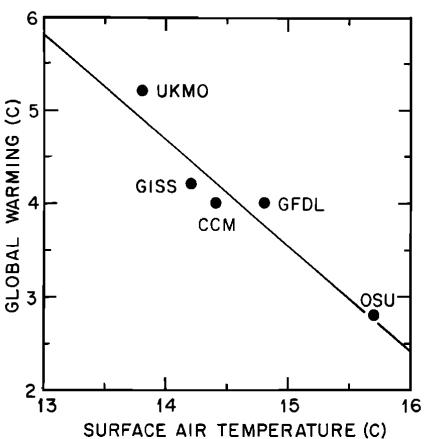
Model	Source	$\Delta T_s$ , °C
UKMO GCM	[Wilson and Mitchell, 1987]	5.2
GISS GCM	[Hansen et al., 1984]	4.2
GFDL GCM	[Wetherald and Manabe, 1986]	4.0
NCAR CCM	(Washington and Meehl, private communication, 1987)	4.0*
OSU GCM	(Schlesinger and Zhao, private communication, 1987)	2.8

Cess and Potter, JGR 1984

This study started with understanding why the models displayed such different results.

- 1) Different sensitivities?
- 2) Response to a direct surfacetemperature radiative forcing?
- 3)Different feedback processes?

# Many of the differences in the models were due to different control climates



This wasn't necessarily true.. Raised more questions than answers.

We found that models with fixed clouds had a lower sensitivity

Suggested doing a CO<sub>2</sub> forcing experiment

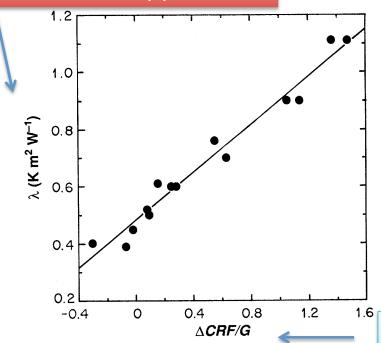
Fig. 1. Global warming, as induced by  $2 \times CO_2$ , plotted against global-mean surface air temperature for the five GCM simulations summarized in Table 1.

### Raising the surface temperature

- We did a 2xCO2 experiment with a radiative convective model that produced a  $\Delta T_s = 1.7^{\circ}$
- The surface temperature response could act as a surrogate simulation
- Based on this an other arguments we proposed and experiment ±2° SST perturbation —limited to 60°N-60°S perpetual July

# Efficient way to look at model feedback processes

#### Global sensitivity parameter



**Fig. 1.** The global sensitivity parameter  $\lambda$  plotted against the cloud feedback parameter  $\Delta CRF/G$  for the 14 GCM simulations. The solid line represents a best-fit linear regression.

- Proposed the experiment to the major modeling groups.. First time to agree on a similar numerical experiment.
  - Until this time protective of results

Cloud feedback parameter

Rather than introduce a forcing to the models and let the models respond, we prescribe the change and let the models produce their forcing.

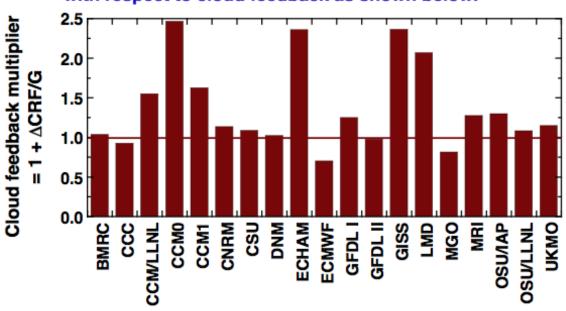
Cess, et al. Science 245 513-516, 1989

Bob Cess gave a presentation a few years ago with this summary plot

#### Snow/ice albedo feedback was surpressed

The good news: The models were in reasonable agreement concerning positive water vapor feedback.

The bad news: The models disagreed significantly with respect to cloud feedback as shown below.



### We named the project FANGIO

 Feedback Analysis of GCMS and In Observations – in honor of the great Italian race car driver



#### Transition to a different way of thinking

- FANGIO and other projects were aimed at understanding atmospheric feedbacks
- Larry Gates (Oregon State University) was hired by LLNL to organize a Center to do diagnostics – DOE had some money to get it started – PCMDI\* was born
  - Model neutral still maintained
- Hired staff



\*Program for Climate Model
Diagnosis and Intercomparison
(PCMDI) – would have been
"Center" for... but DOE couldn't
approve a center
Several moves to take the
program to the Berkeley Lab but

### How to go about comparing model?

 First we thought we should import the models to LLNL to do experiments – first try ECMWF forecast model





- Took too long
- Asked DOE to furnish computer time\* to modeling groups to let them do a similar "experiment" – just simulate a decade using prescribed SSTs
  - Took on international flavor Working group on Numerical Experimentation (WGNE)

<sup>\*</sup> Large computer systems available from the National Magnetic Fusion Computer Center

### Atmospheric Model Intercomparison Project (AMIP)

- All kinds of issues about data –
   formats, structure, media –
- Tried an AMIP II just more of the same
- Slowly the emphasis became more on model differences..
   Rush to make models get the "socially acceptable" result
- Later the oceans used were either a "slab" 50 m thick or prescribed SSTs

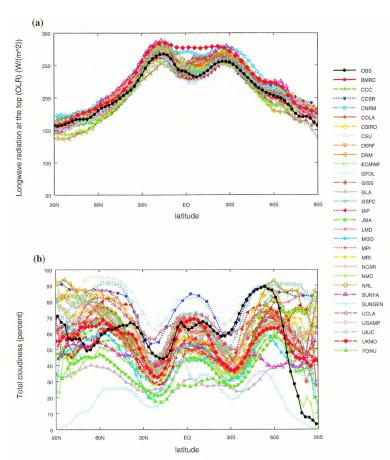


Fig. 7. As in Fig. 6 except for the (a) the outgoing longwave radiation, with observations from the NCEP database (Gruber and Krueger 1984); (b) total cloudiness with observations from ISCCP for 1983–90 (Rossow et al. 1991).

Gates et al. BAMS 1999

#### I felt the coupled ocean was a bit soon

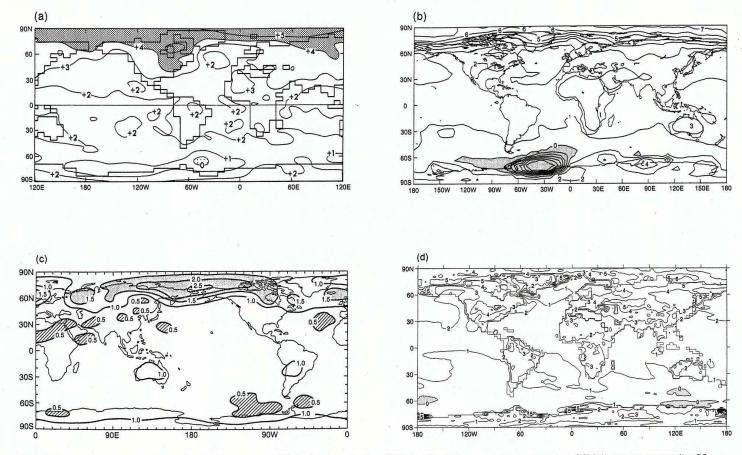
- So many things about the atmospheric models (and the atmosphere) that we didn't understand
- Was it too early to start coupling and running transient experiments?
- CMIP Curt Covey LLNL

# Couple Model Intercomnparison (CMIP)

- Met in 1990 to form strategy for developing the newly emergent global coupled climate models (components of atmosphere, ocean, land and sea ice) being used for the first time for century timescale climate change simulations; organize coordinated experiments, and formulate standards
- Curt Covey kept it alive at LLNL.. seldom get credit

The start of the modern era of multi-model global coupled climate model simulations (IPCC 1992 update to the First Assessment Report)

GFDL (USA), MPI (Germany), NCAR (USA), UKMO (UK); 1% per year CO2 increase



Courtesy of Jerry Meehl

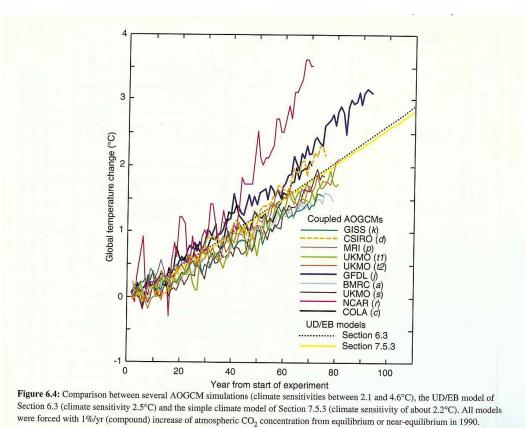
Figure B4: The distribution of the change of surface air temperature (°C) simulated near the time of CO<sub>2</sub> doubling by four coupled ocean-atmosphere GCMs in response to a transient CO<sub>2</sub> increase. (a) The GFDL results are averaged over years 60-80 and referenced to the 100-year average of a control; (b) the MPI results are averaged over years 56-65 and referenced to the corresponding years of a control; (c) the NCAR results are averaged over years 31-60 and referenced to the corresponding control years; (d) the UKMO results are averaged over years 65-75 and are referenced to the corresponding years of a control. (Manabe *et al.*, 1991; U. Cubasch, G.A. Meehl and J.F.B. Mitchell, all by personal communication.)

Multi-model intercomparison for climate change projections in the IPCC Second Assessment Report (SAR, 1995)

The modeling groups supplied time series of globally averaged surface temperature change (from 1% runs)

CMIP started in 1995

These models started with 1990 initial conditions. Did not include aerosols, chemistry, volcanoes, etc.



Courtesy of Jerry Meehl

## Multi-model temperature change in the IPCC Third Assessment Report (2001) from CMIP2

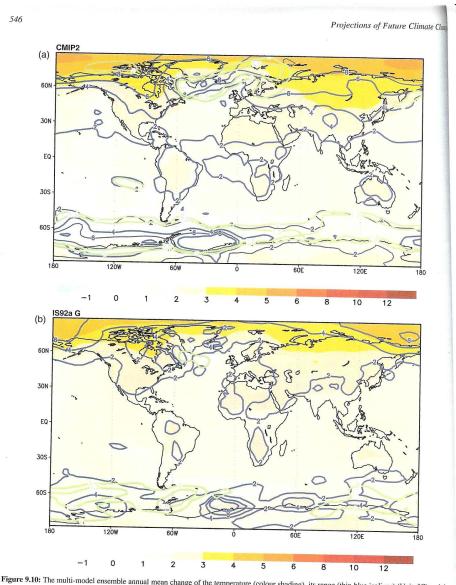
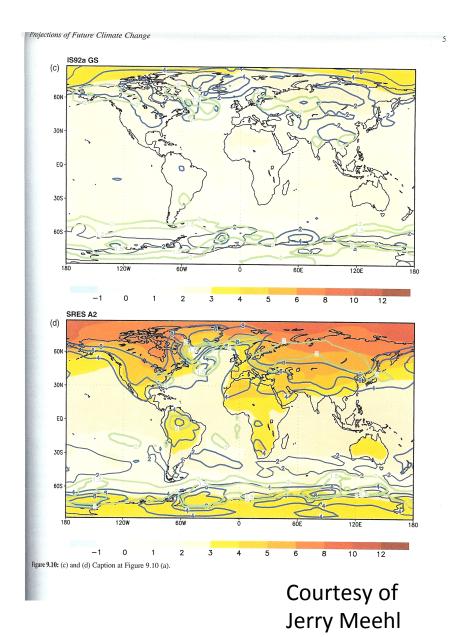


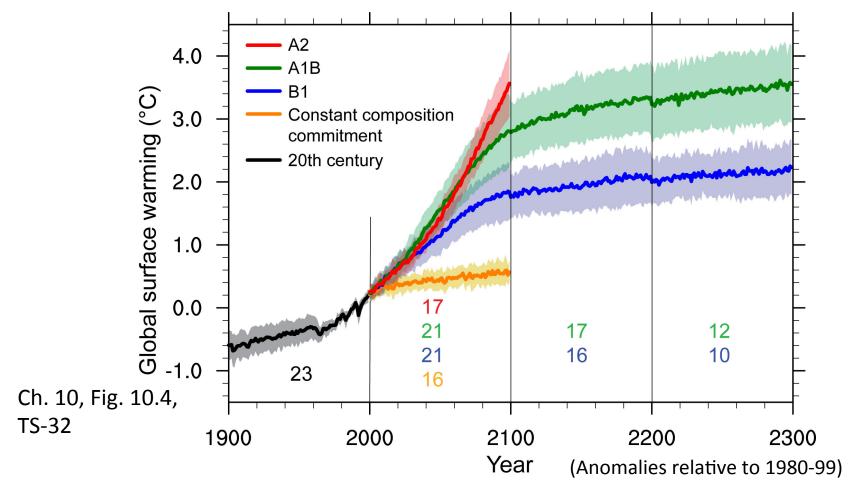
Figure 9.10: The multi-model ensemble annual mean change of the temperature (colour shading), its range (thin blue isolines) (Unit: °C) and the multi-model mean change divided by the multi-model standard deviation (solid green isolines, absolute values) for (a) the CMIP2 scenarios at the time of CO<sub>2</sub>-doubling; (b) the IPCC-DDC scenario IS92a (G: greenhouse gases only) for the years 2021 to 2050 relative to the period 1961 to 1990; (c) the IPCC-DDC scenario IS92a (GS: greenhouse gases and sulphate aerosols) for the years 2021 to 2050 relative to the period 1961 to 1990; (d) the SRES scenario A2 and (e) the SRES scenario B2. Both SRES scenarios 82a which period 2071 to 2010 relative to the period 1961 to



#### CMIP3

- Working Group I IPCC in 2003
  - Asked PCMDI to put together a series of experiments for the 4<sup>th</sup> Assessment
  - Restrictions
    - Data and simulations must be standardized

 Dave Bader (new PCMDI director) was primarily responsible for implementing the CMIP3 data archive



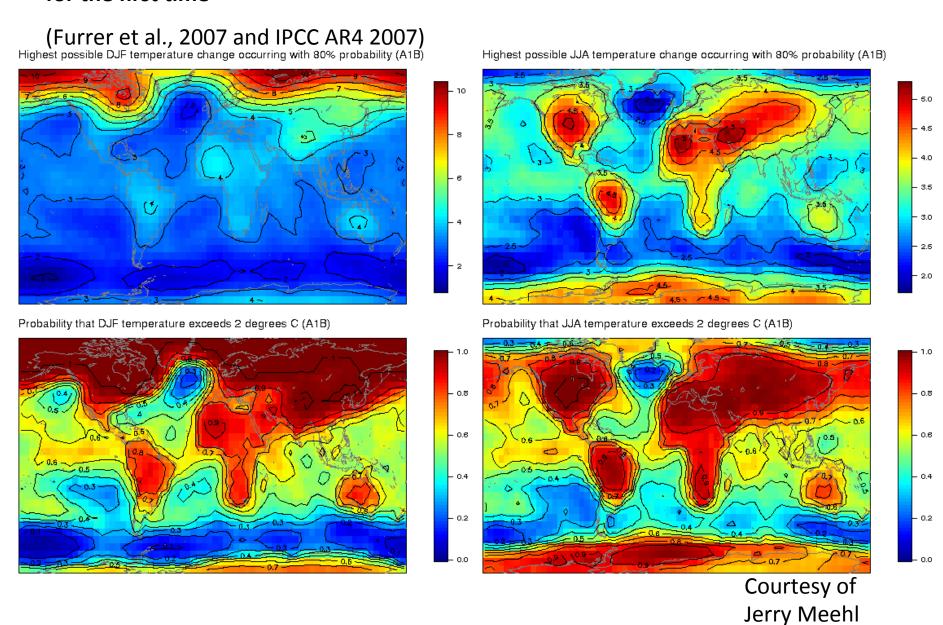
Unprecedented coordinated climate change experiments from 16 groups (11 countries) and 23 models collected at PCMDI (31 terabytes of model data), openly available, accessed by over 1200 scientists; over 200 papers

Committed warming averages 0.1°C per decade for the first two decades of the 21st century; across all scenarios, the average warming is 0.2°C per decade for that time period (recent observed trend 0.2°C per decade)

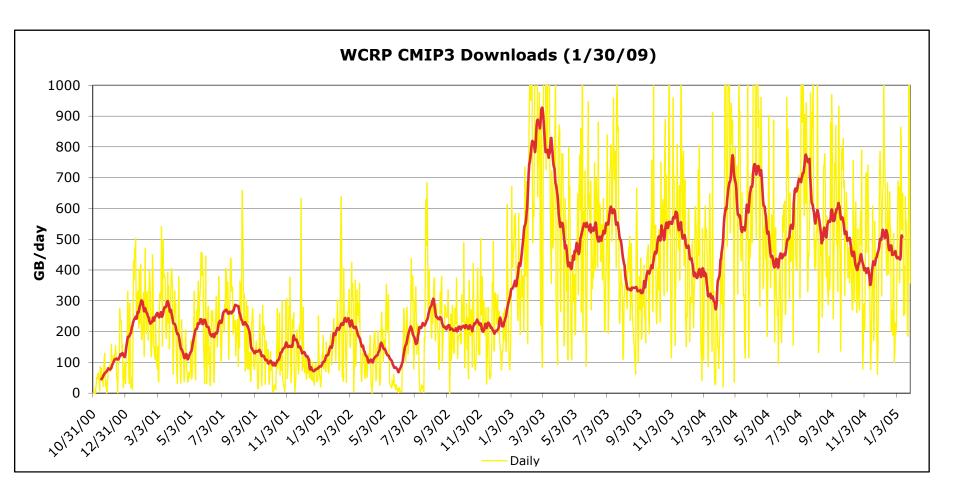
Courtesy of

Jerry Meehl

### With the CMIP3 multi-model dataset, probabilistic climate change is being addressed for the first time

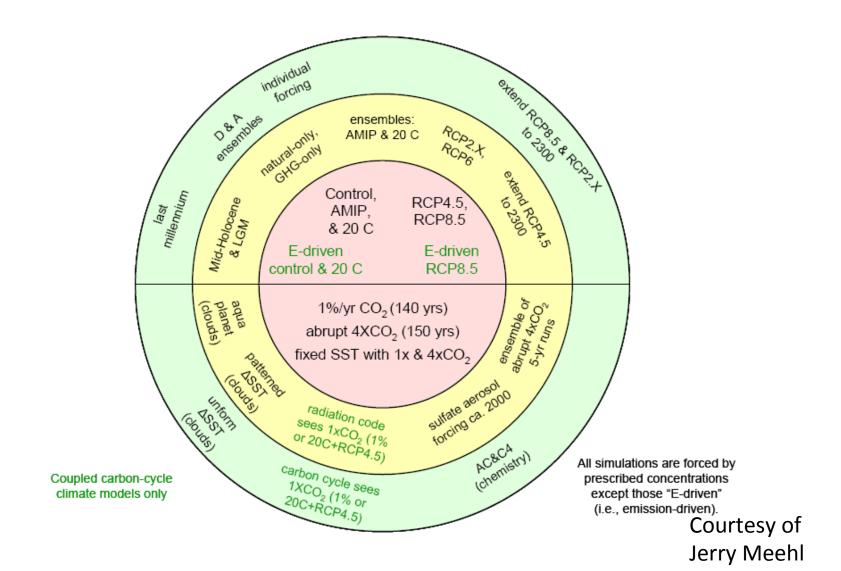


## Downloads have continued to increase after the IPCC AR4 was written



Nearly 1000 peer-review papers using the data

# CMIP5 First Generation Earth System Models (climate change beyond mid-century to 2300):



#### **CMIP5** Decadal simulations

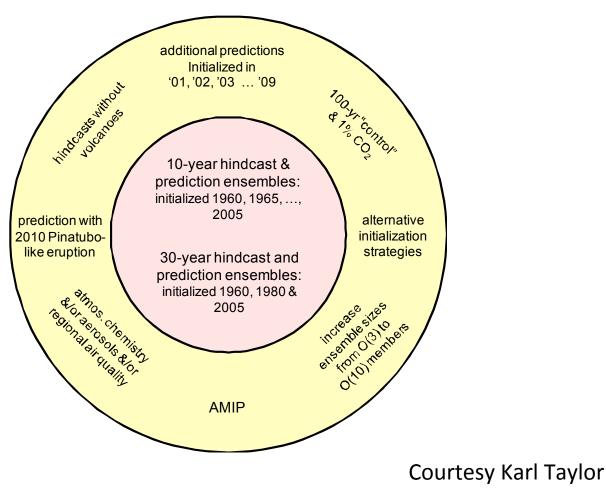


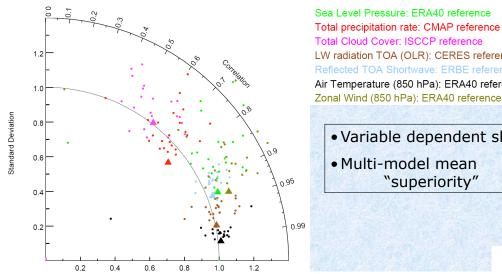
Figure 2. Schematic summary of CMIP5 decadal prediction experiments.

# New Ways to get the data to the scientific community

- AMIP painful transport luckily the volume was low 10's of megabytes
- CMIP3 more painful more volume 20-30TB
  - Kept at a central location
  - "sneaker net"
- CMIP5 required a new way to distribute data 2-3 PB
  - Earth System Grid led by Dean
     Williams (LLNL, PCMDI)



#### Measure of how "good" the models are...



Sea Level Pressure: ERA40 reference Total precipitation rate: CMAP reference Total Cloud Cover: ISCCP reference LW radiation TOA (OLR): CERES reference Reflected TOA Shortwave: ERBE reference Air Temperature (850 hPa): ERA40 reference

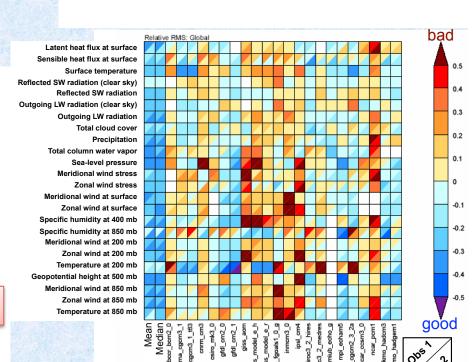
- Variable dependent skill
- Multi-model mean "superiority"

graphically summarizing how closely a pattern (or a set of patterns) matches observations

Taylor Diagram – from Karl Taylor

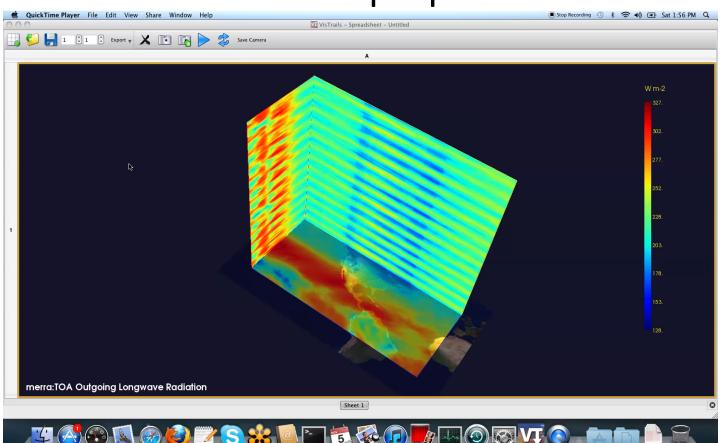
From Peter Gleckler, PCMDI

Mike Fiorino



### Analysis software always an issue

- Everybody wants to use familiar tools
- New tools: run on a laptop



# Interesting study on the sociology of model intercomparison

"The dynamics of coordinated comparisons: How simulationists in astrophysics, oceanography and meteorology create standards for results"

Mikaela Sundberg

Social Studies of Science 2011 41: 107 originally published online 18 November 2010 DOI: 10.1177/0306312710385743

The online version of this article can be found at:

http://sss.sagepub.com/content/41/1/107

### Summary – model intercomparison

- Humble beginnings
- Rapidly grew peer pressure was a factor
- Coupled simulation became fashionable
- Huge impact on the climate modeling/analysis community
- Next stage
  - May be too complicated
  - If successful, will lead to many years of analysis
  - Or may be a yawner
  - Time will tell